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SHIVERING CAPACITY AND PREDICTION OF SURVIVAL TIME

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EXECUTIVE SUMMARY

Prediction models are recognized as an important decision aid in Search and Rescue operations. Differences in body types, severity of exposure, and clothing protection make the prediction of survival time multi-dimensional. While an algorithm can be designed to accept these differences, the validity of the prediction is contingent on the accuracy of the data used to calibrate the model. This is especially difficult in the case of survival time since reliable data are either not available or lack sufficient detail to adequately test the model. Despite these obstacles, a prediction model has been developed (Tikuisis and Frim 1994; Tikuisis and Keefe 1996) and is in use at Rescue Coordination Centres.

To improve the model's predictive capability, knowledge of shivering capacity is required. In many situations (eg., inadequate clothing and wet-cold exposure), the cold stress that confronts the casualty can be defended by the heat produced through shivering. Under this condition, survival time depends on how long shivering can be sustained, which is poorly understood. The purpose of the present study was to measure shivering endurance. To advance "shivering fatigue", volunteer subjects conducted 5 h of high intensity mixed exercise prior to a stressful wet-cold exposure (10°C air with 6 $km \bullet h^{-1}$ wind and a 10°C shower for up to 4 h). Several subjects displayed a rapid drop in their core temperature and this was correlated to a combination of low body fatness and low shivering activity. Subjects with a higher combination were able to greatly reduce their rate of core cooling.

However, when the subject's responses were compared to their control trial (without any prior exercise), shivering capacity was not different and no indication of shivering fatigue was evident. It appears that the model's prediction of shivering endurance is underestimated since its value is determined by the stores of glycogen in the body while the subjects' metabolic measurements indicated that fat was utilized during shivering following the the exercise phase. While the model predictions based on the different body types did not conflict with the observation, model inputs have been modified to lessen the dependence on glycogen stores when fatigue is involved.

1. Background. The deployment of Search and Rescue units is contingent on the unit's ability to reach the rescue site. While every effort is made to reach the site as quickly as possible, information on the status of the casualties would greatly aid logistics and rescue coordination. If contact with the casualties is unavailable, then information on their state of hypothermia (in the case of cold exposure) must be estimated. Years of experience improves the professional's predictive capability; however, with many confounding variables, each rescue operation presents a unique challenge.

One particular concern is the threat of wet-cold conditions which might confront ill-equipped individuals. Such scenarios are endemic to the Canadian landscape and account for a significant number of injuries and deaths if trauma statistics of man-made origins (intentional or industrial) are excluded. Wet-cold casualties rely heavily upon their capacity to shiver to generate sufficient quanties of heat to balance their heat loss. Shivering failure/fatigue has been implicated in the deaths of several individuals that have succumbed to hypothermia under wet-cold conditions (Pugh 1967; Thompson and Hayward 1996). Knowledge of when the shivering capacity diminishes is paramount to improving the prediction of survival time. This report describes an experiment that was designed to address this point and how the results affect the prediction model.

2. Preparatory Research. Thompson and Hayward (1996) reported a study on the thermoregulatory response of individuals exposed to a wet-cold condition while hiking. The experiment was conducted in the field which provided a more realistic environment but at the compromise of control of the ambient temperature and the quality of physiological measurements. Nevertheless, this experiment presented one of the most accurate assessments of thermoregulation under 'real' wet-cold conditions. Another study recently reported by Weller et al. (1997) also involved a wet-cold walk but conditions were not as severe to produce the level of hypothermia achieved by Thompson and Hayward.

In the Thompson and Hayward study, subjects walked in 5°C air for up to 5 h under a dry condition for the first hour and were then exposed to cold rain for the balance. Out of the 18 subjects that participated, 5 lasted the full duration and experienced a mean drop of about 1.2°C in rectal temperature (T_{re}) over a period of 2 h after the rain began. The initial period of deep body cooling was followed by a 1 h period of stabilization and a subsequent drop in T_{re} over the last hour of about 0.4°C. Interestingly, the metabolic rate during the last hour did not rise as expected due to further decreases in body temperatures (Tikuisis 1995; 1997). Whether this indicates a degradation in shivering capacity is uncertain. One subject that failed to complete the full duration experienced an abrupt cessation of shivering after 2.5 h in the rain followed by a rapid drop in T_{re}. Thompson and Hayward termed this event "shivering fatigue" which might have occurred with other subjects had they been tired at the start of the wet-cold exposure.

The main lessons learned from this study were that a select group of highly motivated individuals must be recruited to endure the harsh conditions of a realistic wet-cold exposure and that careful measurements must be taken to ensure that shivering fatigue is authentic. With regard to the former, screening procedures must be strict and attention must be given to maintaining the subject's motivation during the experiment. This can be achieved by keeping the subject well-informed and occupied during the experiment. With regard to accuracy, best measurements are obtained in a laboratory setting and since accuracy is a priority, the challenge is to create a realistic scenario in the artifical environment. Regardless of where the experiment is conducted, the level of anxiety experienced by the subject can never match a true survival situation, hence the results must be interpreted accordingly.

3. <u>Experimental Strategy</u>. The focus is on the individual's shivering capacity. Presently, the prediction model assigns a metabolic reserve (RES) based on glycogen stores in the body. Its value is calculated from the individual's muscle mass which is estimated from percent body fat and body mass (Newsholme and Leech 1983). Shivering is assumed to continue until RES is depleted (Wissler 1985). Further, if the individual is fatigued due to

prior exercise and has not replenished metabolic stores, it can be reasonably expected that this will diminish shivering capacity. From a modelling perspective, exercise fatigue corresponds to a reduced value of RES. It is presently assumed that shivering endurance, and not the intensity of shivering, is affected by exercise fatigue.

To test this hypothesis experimentally, a comparison of the shivering capacity should be conducted on individuals in a well rested *vs* fatigued state. The level of exercise fatigue should correspond to the depletion of the RES. Another important consideration is the activity during the wet-cold exposure. Previous investigators have examined the effect of exposure conditions on thermoregulatory response, i.e., choosing a dry-cold condition as their control trial. Unfortunately, in purported cases of shivering fatigue, it cannot be ascertained whether shivering would have also failed if the subject was at rest during the wet-cold exposure. Whether these cases of shivering fatigue are due to the exposure condition or to the individual's susceptibilty to cold is unclear. Hence, an appropriate comparison would be one where the subject is inactive during the exposure but is well rested in one trial and fatigued in another before exposure.

Fatigue can be induced by a series of high intensity aerobic and resistance exercises to approximate vigorous outdoor activity involving several different muscle groups. It is recognized that muscle recruitment during these exercises differs from that during shivering. However, the focus is on the type of fatigue that outdoor enthusiasts might experience. Two trials are involved, one with pre-exposure exercise (Fatigue) and the other without (Control) so that shivering responses can be compared using a repeated measures design.

4. Experimental Protocol. Thirteen active, non-smoking male subjects (27.3 ± 8.2 yr) participated in the experiment. Baseline measurements (mean ± SD) taken included physical characteristics such as weight (74.7 ± 7.1 kg), height (1.77 ± .05 m), body fat (14.0 ± 4.6%), maximum aerobic power (51.3 ± 4.3 ml $O_2 \bullet min^{-1} \bullet kg^{-1}$) and maximum heart rate (196 ± 13 bpm) using a standard exercise test to exhaustion on a treadmill, and 1 RMs (Repetition Maximum, i.e., maximal exertion in one continuous motion) on 5 different

weight lifting apparatus. All individual trials were counterbalanced to avoid any ordering effects and spaced one week apart. Subjects were also required to observe the following restrictions regarding diet, exercise, and medication. Food intake was the same on the morning of each experiment, exercise was prohibited for 24 h beforehand, and trials were cancelled if medications were taken 48 h beforehand.

Aerobic exercises were conducted for 1 h each on cycle, rowing, and treadmill machines separated by additional 1 h sessions of resistance exercises for a total of about 5 h of high intensity exercise. The aerobic exercises began with a warmup and work rates were raised within 5 min to a steady state level requiring 80% of the subject's maximum heart rate. Each session of the resistance exercises consisted of 3 rotations among 5 different weight lifts (leg extension, bench press, lat pull downs, leg flexions, arm curls). Each lift was repeated at approximately 70% of the subject's 1 RM to fatigue. Following each rotation of the 5 lifts, the subject conducted 20 situps on a 6° inclined board. The subject was given water to drink *ad libitum*, and if necessary was required to consume an amount of water equivalent to the weight loss during exercise to maintain hydration. No other drink or food was consummed during the entire trial (including the cold exposure phase).

Following the exercise phase or beginning in a well rested state for the Control trial, subjects dressed down to dry t-shirts and shorts. They were then instrumented for rectal (T_{re}) and skin (T_{sk}) temperature measurements including heat loss, ECG electrodes over the chest, and EMG electrodes over the vastus lateralis and pectoralis muscles. Finally, an intravenous catheter was inserted in the anti-cubical vein of the non-dominant arm for blood sampling.

Following instrumentation, the subjects were given neoprene gloves and boots, and a rainhat following the example of Pugh (1967) to avoid excessive discomfort. They were then seated on a webbed chair in the cold chamber. The subjects were first exposed to calm air at 10°C for 30 min, and then to a 6 km•h^{-1} wind and a 10°C shower of ~ 920 ml•min^{-1} directed on their back for up to an additional 4 h.

The following measurements were taken during each half hour: hand-grip strength with a dynanometer at 5 min, O_2 consumption and CO_2 production between 20 and 30 min, and a blood sample at 25 min. In addition, mental performance tasks were conducted between 5 and 18 min and will be reported elsewhere. The trial ended if requested by the subject, 4 h of the wet-cold exposure had elasped, or T_{re} reached 35.0°C.

Standard heat balance calculations and statistical analyses of variance for repeated measures (Control *vs* Fatigue) were used to analyze the data. The acceptance criterion for significant differences was at the 0.05 level (Greenhouse-Geisser adjustment). Regression analyses were also applied to test for significant correlations among various variables.

4. Results. The total aerobic expenditure was 1747 ± 177 kcal and the total mechanical work performed on the resistance exercises was 8403 ± 1401 kg•m plus 120 inclined situps. Six Control and four Fatigue trials ended early because T_{re} reached the termination point of 35°C. Three Control and six Fatigue trials ended early because of subject request due to intolerable discomfort (cramping and/or headache). However, there was no significant difference ($p = 0.071$) in durations between the Control (197 ± 72 min) and Fatigue (172 ± 68) trials (see Fig. 1). Regression analyses indicated that duration was correlated positively to body fatness (%BF; $r = 0.716$) and to the metabolic rate (MR) during exposure ($r = 0.653$). The multiple regression [duration (min) = $- 79.5 + 9.96 \bullet \%BF + 0.859 \bullet MR$ ($W \bullet m^{-2}$); $R = 0.862$] was also significant. A significant main effect of duration was found in most cases and a significant main effect of trial was found for the respiratory exchange ratio and heart rate. Details on these differences in measurements between the two trials will be reported elsewhere.

The overwhelming conclusion of this study is that there is no difference in the physiological variables that impact shivering capacity in a stressful wet-cold exposure in a well rested condition *vs* one where 5 h of high intensity mixed exercise is performed beforehand. In addition, there was no evidence of "shivering fatigue" during the exposures. There were, however, large

differences in MR between subjects, but not within. No measured physical or physiological characteristic, including age, can be traced to the more than 3-fold difference seen in MR between the subjects. Insofar as the shivering drive is concerned, higher signals should be expected from individuals with greater core cooling (Brown and Brengelmann 1970), yet low MR values persisted. Adaptive, behavorial, and/or psychological factors remain to be explored.

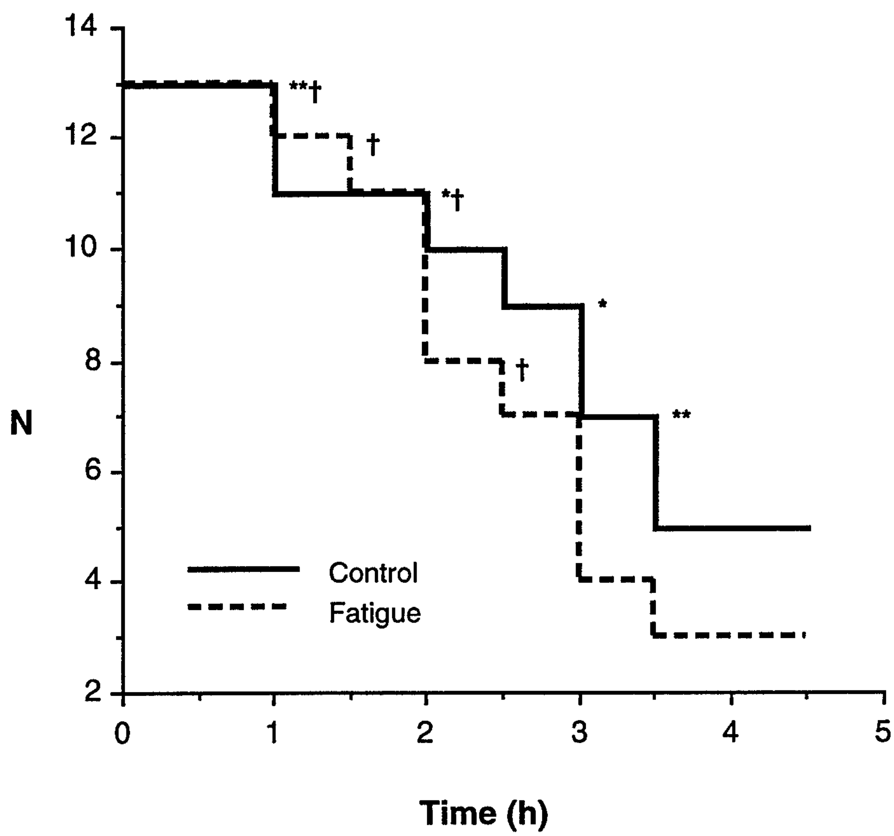

Fig. 1. Number of subjects shown against the duration of exposure. * and † denote the termination of Control and Fatigue trials, respectively, when T_{re} reached 35.0°C.

The rates of decrease in T_{re} in 2 of the subjects (~ 2.5°C•h^{-1}; see subjects 12 and 13 in Fig. 2) matches very closely with the rates reported by Pugh (1967) and Thompson and Hayward (1996) which they attributed to shivering fatigue. Further, the present values occurred during the Control exposure when the

subjects were in a rested state. Pugh (1967) suggested that victims of accidental hypothermia in wet-cold conditions are generally lean and upon losing their ability to continue exercising (eg., hiking) due to exhaustion, succumb to hypothermia. Low body fat is clearly implicated in all studies including our own. However, it is also evident from our study that rapid core cooling is not contingent on exercise fatigue as noted above. The amount of aerobic activity in Pugh's study was not higher than in our Fatigue trial nor of longer duration. One of Pugh's subjects was able to stabilize his core temperature above 35°C and another exhibited a rapid drop during rest following exercise. Since no control trial was conducted, it would be speculative to conclude that exercise fatigue in this case was the main cause of rapid core cooling.

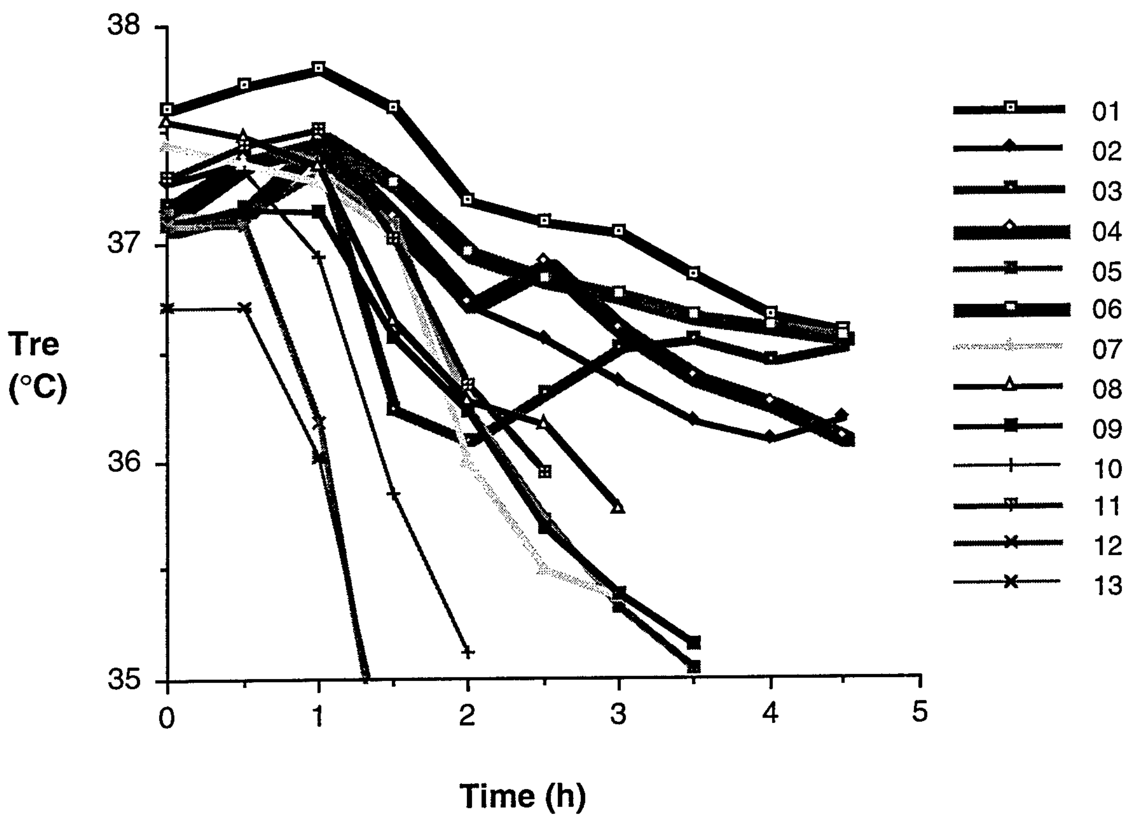

Fig. 2. T_{re} plotted against time of exposure for each subject (indicated numerically) during the Control trial. Thin, medium, and thick lines refer to different levels of body fatness (< 10%, 10 - 20%, and > 20%, respectively).

Hypoglycaemia, which would affect shivering capacity (Haight and Keatinge 1973), was not a factor in our study (blood glucose values exceeded 3 $mmol \bullet l^{-1}$) and seems unlikely in Pugh's and Thompson and Hayward's study (1996) given the amounts of exercise performed.

5. Discussion. The above interpretation of the results should not be misconstrued as suggesting that exercise fatigue has no impact on shivering capacity; it should at some point but not within 4.5 h of cold exposure. Our study establishes the minimum conditions or benchmark that should be exceeded to achieve an effect, i.e., by exceeding the combination of 5 h of high intensity mixed exercise and 4 h of a stressful wet-cold exposure without any replenishment of metabolic substrates. The wide subject variability in the rate of core cooling observed under conditions below the benchmark can be mostly explained by low body fatness and a low shivering intensity. However, the latter is not necessarily the result of exercise fatigue, at least at the levels applied in this and the above cited studies. It appears that certain individuals simply lack the shivering "drive" usually observed in others having similar physical and physiological characteristics.

The lack of a difference in the shivering response between the Control and Fatigue trials indicates that shivering endurance is probably underestimated in the prediction model of survival time. The metabolic reserve calculated for the average of the subjects in this study is 1646 kcal. This value almost matches the amount of aerobic work performed for the Fatigue trial, yet the subjects did not display any detriment in their shivering capacity. At what point exercise fatigue impacts on shivering remains unknown.

The experimental results also confirm that shivering is not solely dependent on glycogen stores as indicated by the lower values of the respiratory exchange ratio during the Fatigue trial. Hence, the shivering endurance threshold based on RES is probably underestimated; yet, use of this value in several applications of the model has not resulted in any gross underestimations of survival time. This might simply indicate that the other parameters in the model compensate for the reliance of shivering endurance on glycogen stores alone. However, until the effects of exercise fatigue on shivering capacity are

fully quantified, we are reluctant to change the model algorithm at this time. It would be more prudent, and conservative, to lower the model's reduction of RES due to exercise fatigue.

Consider for example, the predicted body cooling for 20 and 50% reductions in RES. Under the experimental conditions, the model predicts times of 4.6, 4.0, and 3.2 h to a T_{re} of 34°C for no fatigue, a 20% reduction, and a 50% reduction, respectively, for the average subject in the study. If applied only to the leanest subjects, times of 3.4, 3.0, and 2.4 h would be predicted. For the fattest subjects, times of 7.5, 6.5, and 4.9 h would be predicted. The predictions for a 20% reduction in RES do not conflict with the observation and will be designated as a "tired" state (eg., following several hours of work/exercise as in this study) for modelling purposes. The 50% reduction in RES will be designated as an "exhausted" state (eg., inability to continue work/exercise). Although arbitrary, these designations are more realistic than the previous assignments of fatigue in the model. Clearly, further work is required to verify this change and to test the "exhausted" designation.

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The accuracy of prediction models of survival time for cold exposure depends heavily on the estimation of shivering capacity which is poorly understood. The purpose of this study was to measure shivering endurance which was hypothesized to diminish through pre-exposure exercise. Thirteen healthy and fit males (mean ± SD; age = 27 ± 8 yr; height = 177 ± 5 cm; weight = 75± 7 kg; body fat = 14 ± 5%; VO_{2max} = 51 ± 4 ml• kg^{-1} • min^{-1}) participated in an experiment designed to test their shivering response following 5 h of high intensity mixed exercise during which only water was consumed. Following exercise for the fatigue trial or beginning in a "fresh" state for the control trial, and instrumentation for physiological monitoring (rectal and skin temperatures, metabolic rate, heat loss, heart rate, EMG), subjects assumed a seated position in a 10°C air environment wearing shorts, t-shirt, rainhat, and neoprene boots and gloves. After 30 min, the subjects were showered continuously with cold water (~ 920 ml•min^{-1} at 10°C) on their backs accompanied by a 6 km•h^{-1} wind for up to 4 h. Three subjects lasted the complete duration for both trials with final mean ± SD rectal temperatures of 36.43 ± 0.21 and 36.08 ± 0.48°C for the control and fatigue trials, respectively. Values for the remaining 10 subjects varied from 35.0 (termination point - 8 cases) to 36.7°C over durations from 60 to 270 min (mean ± SD were 175 ± 68 and 144 ± 44 min for the control and fatigue trials, respectively). While shivering fatigue was not observed, there were vast differences in the shivering response of the subjects which, in addition to body fatness, influenced duration. The results also indicate an over-reliance on glycogen stores for shivering in the present prediction model based on the subject's utilization of fat during shivering in the fatigue trial.

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shivering; hypothermia; thermoregulation; heat debt; rectal temperature